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MINERALS OF THE KOLA PENINSULA

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Since 1920 the Mineralogical Museum of the Academy of Sciences of the USSR, and the Research Institute of the North have been jointly investigating two massives of alkaline rocks in the central part of the Kola Peninsula, lying between 67°35′ and 67°55′ north latitude. The districts are known as Hibina- (or Umptek), and Lujavr-Toundra (or Lujavr-urt).

The total area of the massives is 1600 square kilometers; a barren, badly dissected country, 1200 meters above sea level, covered with forests and swamps (*taiga*), and free from snow only during the two or three months of polar summer.

In the course of six years work, the various parties of the "Expeditions" (varying in personnel from two to eleven men) have covered about 3000 kilometers and collected over five tons of scientific material. The rare and interesting minerals found represent approximately one hundred and fifty different localities. The conditions under which the work was carried on were exceedingly trying owing to the bitter cold (snow fell as early as August 9), the swarms of insects and the absence of roads or even pathways, not to mention lack of habitations. The principal bases were the railway stations of Hibina, Imandra, and Belaya.

Hibina-Toundra and Lujavr-urt occupy first rank among mineral localities, not only for the beauty of the specimens, but also for the peculiarity of the minerals, the abundance of rare combinations, and their interesting genetic relationships. The rich mineralogical material collected is now exhibited in all its splendor in the Mineralogical Museum of the Academy of Sciences.

Our experience has been that every new journey to this field develops new mineralogical discoveries since a large number of gorges and portions of plateaus have not yet been visited. The study of this material is still being pursued by numerous workers in the Mineralogical Museum; new facts are being discovered, so that our knowledge of these massives is far from being complete.[1]

GEOLOGY

The massives of Hibina-Toundra and Lujavr-urt consist of nephelinitic rocks. The western massive—Hibina-Toundra—is composed of a variety of light-colored nephelite syenites bordered by zones of sedimentary rocks and gneisses, which are metamorphosed at the contact. These rocks are cut by segregation veins.

A deep meridian lake separates this massive from the eastern one—Lujavr-urt—composed of schistose lujavrite (variety of nephelite syenite). From orographic and petrographic standpoints both massives have the shape of a horse shoe, opening to the east, and consisting of concentric ridges of mountains, cut through by snow obstructed passes.

The mineral localities follow the same concentric zones, and are peculiar to definite types of syenites. In Lujavr-urt the zone of pegmatite veins containing rare minerals is to be found at a height of 600 to 700 meters, with an extension of 50 kilometers.

HIBINA MINERAL ASSEMBLAGES

Twenty-seven typical mineralogical segregations are distinguishable in both massives. These are shown in Table I.

The contact minerals of the Hibina massive (Group B) are found in a zone around the whole massive, and appear also at times in the highest central points. The margin of the massive consists of rocks of the type of umptekite, lying near the contact, and by coarse-grained hibinite. The hibinite passes into lamellar nephelite syenites (including minerals of Group R).

The minerals of the magmatic phase (Group A) are limited by a deep furrow separating the outer zones from the central part of the massive. The central part is crossed by veins of Group O; while the line of the valley of Koukiswumchorr is bordered by veins of Group P. The middle and inner slope of the massive is occupied by Group G.

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[1] About fifty papers have been published in various journals on special investigations of the Expeditions. The general summary appears in three volumes: the first, with a map of Lujavr-urt and the routes appeared in 1925. The second volume, to appear in 1926, will contain the geological and petrographical results, with a description of the localities. The third volume will describe the mineralogy and geochemistry of the massives.

TABLE I. GENETIC TYPES OF HIBINA-AND LUJAVR-TOUNDRA.

According to W. Brögger	Temperature	Phases of Process	Characteristics	I Zr, and Rare earths Predominate; Lamprophyllite Group	II Ti Predominates Astrophyllite Group	III Ti Predominates Sphene-Ilmenite Group	IV Rare earths, Zr, and Ti absent. Feldspar-Zeolite Group	V Endocontact Group **B**	VI Lujavr-urt Group **L**
First: Magmatic Phase	Near 1000°	A Magmatic	Amazonite, with large masses of black Aegirine I, and Arfvedsonite. Aegirine II	1. Rinkolite a. With Aegirine b. With Aegirine and Eudialyte. 2. Aenigmatite, Mesodialyte. a. With rare Lamprophyllite. 3. Lamprophyllite-Mesodialyte, with (Aegirine II).	**R** b. Reaction rim of Astrophyllite.	9. Brown Sphene.	13. Hornblende-Amazonite 14. Aegirine-Amazonite 15. Sodalite-Arfvedsonite. 16. Feldspar-Aegirine a. elaeolite absent b. with elaeolite	20. Loparite-Eudialyte or Eucolite 16c. Fedspar with Aegirine, and Ramsayite. 16d. Feldspar with Aegirine and Loparite.	21a. Aegirine-Eucolite-Ramsayite, with Lamprophyllite-Murmanite (and Sodalite).
		B Epimagmatic, Pegmatitic.	Sphene, Astrophyllite, and Apatite	**J**	4. Astrophyllite a. With Aegirine and Mesodialyte b. With Hornblende 5. Eucolite, with Albite, Aegirine, and Hastingsite 6. Feldspar-Astrophyllite	10. Yellow Sphene. 11. Eucolite a. With Sphene b. With Ilmenite 12. Pectolite-Astrophyllite. 17a. Apatite with Sphene **A**	**W** 17b. Apatite with Magnetite or Biotite	22. Feldspar-Quartz	21b. Lamprophyllite-Murmanite 27. Schizolite-Ussingite
Second: Pneumatolitic Phase	500°	C Pneumatolytic	Yellow-Brown Feldspar, and dark minerals	Feldspar Veins (with Fluorite) (Largely Albite) a. With Zircon, and some Arfvedsonite		**O** b. With Ilmenite, local Arfvedsonite (Zircon).	c. With Biotite	25. Albite with Biotite and Zircon 23. Corundum-Pyrrhotite (with Anatase) 24a. Albite-Analcite with Neptunite and Elpidite.	24a. Analcite (Sodalite), Aegirine with Neptunite.
Third: Hydrothermal phase	350°	D Hydrothermal	Natrolite (red)				18. Chalcedony (Calcite II)		
			Aegirine III	8. Natrolitic veins and masses		**P**	8d. Analcite	24. Natrolite-Neptunite (with Aegirine	24b. Natrolite-Neptunite (with Aegirine).
	200°		Natrolite: white, and reddish. Zeolites.	a. With Zircon	b. With Astrophyllite.	c. With Ilmenite	e. With Aegirine f. With Hydrargyllite.		
Fourth: Fluo-carbonate phase	100°		Yellow flint.				19. Flint Calcite III		

Genetic History. The regular distribution of genetic types is connected with the mode of origin and method of cooling of these magmatic masses. As yet the studies have not been completed, and one must construct hypotheses for the explanation of the observed correlations.

Careful study of the course of the geological processes of Hibina-Toundra show two very marked periods in the history of the mineralogical events. The first period separates the magmatic and pegmatitic stages, which in all cases was marked by the formation of immense radiated masses of aegirite of the second generation. At this time the earlier formed magmatic minerals became unstable: aenigmatite was replaced by astrophyllite, elatolite was removed, the stream of volatile elements increased, and the formation of minerals of lower specific gravity began.

This was due not so much to the variation of temperature as to the unexpected lowering of pressure. This type of phenomena was especially characteristic of the central zone of Hibina, where we undoubtedly have to deal with the region in which the formation of the minerals proceeded under decreased pressure.

The second period in the geochemical history of the massive was determined by the liquation of the steam (about 300–400°C). From then on appeared the typical hydrothermal veins (zeolites).

It is more difficult to trace the genetic processes in Lujavr-urt, as this Toundra has not been sufficiently studied. Nevertheless, one is attracted by the great resemblance of the lujavritic pegmatities with the contact zones of Hibina-Toundra.

MINERALS PRESENT

About ninety minerals have been found in the nepheline syenites and their endocontact zones. These are listed below. Those identified only under the microscope are placed in parentheses, while the more interesting ones are given in italics.

Sulfides (6): chalcopyrite, galena, molybdenite, pyrite, pyrrhotite, sphalerite.

Haloids (2): fluorite, yttrocerite.

Carbonates (4): calcite, *calcioancylite*, *elatolite*, malachite.

Phosphates (1): cerium apatite.

Oxides (15): agate, (anatase), chalcedony, (corundum), flint, (hydrargyllite), ice, ilmenite, limonite, manganese oxides, quartz, (quartzite), (rutile), (spinel), zircon.

Silicates (45): actinolite, aegirite, (aegirite-augite), (albite), analcite, (andalusite), (andesine), anomite, anorthoclase, arfvedsonite, barkevikite, biotite, cancrinite, cataforite, chabazite, chlorite, chrysocolla, (diopside), epidote, epistilbite(?), (garnet), *hackmannite*, hastingsite, heulandite, hornblende, hydronephelite, kaolinite, mesolite, microcline, natrolite, nephelite, nosean(?), olivine, orthoclase, *pectolite*, pyroxene-titaniferous, *schizolite*, (serpentine), (sillimanite), sodalite, *taeniolite*, thomsonite, *ussingite*, (wollastonite), *yuksporite*.

ZIRCONO-TITANO-SILICATES (15): Eudialyte group: *aenigmatite*, *astrophyllite*, eucolite, eudialyte, låvenite, *lamprophyllite*, *lovchorrite*, mangan-neptunite, mesodialyte, *murmanite*, *ramsayite*, *rinkolite*, rosenbuschite, *titano-elpidite*, wöhlerite.

TITANATES AND TANTALATES (4): *loparite*, perovskite(?), (pyrochlorite ?), sphene.

DESCRIPTIONS

AENIGMATITE. This is very common in several types of segregation veins, forming large irregular crystals weighing several kilograms. It is accompanied by aegirite, microcline, nephelite, and eudialyte. Astrophyllite and aegirite when bordering this mineral, sometimes replace it entirely, forming a variety of reaction-rim called *coronite*.

ASTROPHYLLITE. Likewise very common in large golden-yellow plates, or fine filiform and fibrous masses, associated in the latter form with pectolite, sphene, and natrolite. Masses weighing ten kilograms were found.

CALCIO-ANCYLITE. This mineral is similar to ancylite from Narsarsuk, Greenland, in its crystallographic and physical properties. It occurs in small yellow, tinged with gray or brown, crystals, coating the cavities of an unidentified mineral, associated with zircon, natrolite, ilmenite, acicular aegirite, and occasionally with small quantities of yttrocerite.

CERIUM-APATITE. Green apatite is rather common in nephelite syenite veins in masses of probably commercial importance. It contains about 3.18% of the rare earths of the cerium group. It occurs associated with magnetite, nephelite, biotite, aegirite, sphene, and microcline.

ELATOLITE. Under this name, A. E. Fersman has described traces of a mineral filling cavities about 8 cm. in length with an arborescent crystalline skeleton. Crystallographic examination indicates an origin from primary calcium carbonate stable at a temperature above 1000°C, and disappearing entirely at a decreased pressure.

EUDIALYTE GROUP. In variety of color and abundance of crystal forms, the members of the eudialyte group have proved exceedingly interesting. It is found sometimes in large masses. There are many types, from violet-red eudialyte to the brown eucolite.

The change of color follows the increase in specific gravity, increase of rare earth content, and gradual change of optical sign (+ to −), with the intervening pseudo-isotropic variety called mesodialyte.

HACKMANNITE. Common in Lujavr-urt, associated with sodalite. It has a violet-red tinge on a fresh fracture, which rapidly disappears after a few minutes exposure in the open air.

LAMPROPHYLLITE GROUP. Lamprophyllite is one of the most remarkable of the Hibina and Lujavr-urt minerals. It occurs in poorly developed crystals up to 20 cm. in length, or in stellate groups, with a perfect cleavage, and a semimetallic luster. Its exterior resemblance to astrophyllite is very striking so that it is very difficult to distinguish them without testing. It occurs associated with eudialyte, aegirite, and rinkolite. The mutual replacement of zirconium by titanium, and CaO by SrO and BaO is characteristic, with corresponding variations in optical properties.

LOPARITE. It is a black mineral, with a metallic luster, forming pseudocubic penetration twins. The principal forms are (100) and (111). It occurs in umptekite along the line of contact, associated with eudialyte, aegirite, ramsayite, and sphene.

MANGAN-NEPTUNITE. This mineral was found locally in the contact zone of the Hibina massive, in dark red, almost black crystals, associated with fibrous aegirite, natrolite, and analcite. It occurs also in the pegmatites in the lujavrite of Lujavr-urt, associated with aegirite, natrolite, eucolite, and ramsayite.

MURMANITE. This is a violet, scaly mineral with a perfect micaceous cleavage, and a semimetallic luster, occurring both in Hibina-Toundra (rare), and in Lujavr-urt (in beautiful plates of considerable size).

PECTOLITE. It occurs in large masses in gneissic pegmatites or nephelite syenites. Numerous analyses show it to possess a variable composition. It is accompanied by sphene, fibrous astrophyllite, aegirite, biotite, natrolite, and more rarely by grains of fluorite, galena, and sphalerite.

RAMSAYITE. It differs from lorenzenite in the absence of zirconium. It occurs as large, dark brown, well developed orthorhombic crystals up to 3 cm. in length. It is associated with feldspar, nephelite, aegirite, and eucolite. It has been prepared artificially.

RINKOLITE. It is very common in the Hibina-Toundra, forming elongated and lamellar crystals of yellowish-green color, which may attain a length of 20 cm. At one locality, large brown, colloidal masses weighing hundreds of kilograms were found (*lovchorrite*). It is related to mosandrite and rinkite, resembling the latter in paragenesis and exterior appearance.

SCHIZOLITE. This mineral is very rare, and occurs only in ussingite in single crystals.

TAENIOLITE. It occurs in laminae resembling the mineral from Narsarsuk, Greenland, and was found in the valley of Mannepahk in Hibina-Toundra, in the contact zone.

TITANO-ELPIDITE. It occurs in small quantities in the contact zone associated with albite and the oxides of manganese. It differs from elpidite from Narsarsuk, Greenland, in having titanium prevailing over zirconium, with corresponding differences in optical properties.

USSINGITE. It was found in a boulder in Lujavr-urt with aegirite and schizolite. Its composition and properties are identical with the mineral from Kangerdluarsuk, Greenland.

YUKSPORITE. It is a pink lamellar, or scaly mineral, which appears to be a member of the pectolite group, but contains more sodium. It is found intergrown with sphene, and accompanying pectolite, astrophyllite, biotite, and aegirite.

GEOCHEMISTRY

From the geochemical standpoint the massives are of great interest because of their characteristic elements. The table below lists these in order of decreasing importance. The prevailing elements which determine the type of geochemical province are printed in heavy type:

(I) O, F, **Na**, Mg, Al, Si, P, Cl, K, Ca, **Ti**, Mn, Fe, **Zr**, Ce group.
(II) H, C, S, Cu, Mo, Pb, Zn, Sr, Ba
(III) V, Y, Nb, Hf, Ta, Th, Li (Au?)

The elements of the middle atomic weight strikingly predominate, and the absence of light volatile metalloids and heavy metals is also marked. Even numbered elements, especially those of the fourth periodic group, prevail. Compared with other great alkaline regions the following features are noteworthy: the predominance of titanium over zirconium (as it is in Greenland and the Langesundfiord); and the prominence of phosphorus, the cerium group of rare earths, strontium and barium.

While the geochemistry and mineralogy of the contact zones resemble the assemblages of Narsarsuk, Greenland, the central part of Hibina-Toundra more nearly approaches the dikes of alkaline rocks in that country. The minerals of Lujavr-urt, however, somewhat resemble those of Pilandsberg in South Africa. Without analogy, and quite exceptional, are the ramsayite pegmatites of Lujavr-urt, in which are to be found assemblages of rare beauty consisting of hackmannite, elatolite, lamprophyllite, ramsayite, eucolite, and murmanite—six of the characteristic minerals of the Kola Peninsula.

Tables II and III summarize some of the more important chemical analyses, physical and optical properties of a number of the minerals of this region.

Table II. Selected Analyses of Some of the Minerals from Hibina-and Lujavr-toundra

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
SiO_2	.....	59.17	46.57	48.05	55.44	27.66	42 02	52.68
TiO_2	.....	.....	1.01	3.13	5.28	20.83	8.34.	18.21
ZrO_2	.....	.....	14.49	8.97	.....	12.40	.....	.....
Ce_2O_3	47.27	.....	.....	2.54	.....	0.50	.....	.....
Yt_2O_3	0.74	.....	.....	.....	.....	.....	.....	.....
Al_2O_3	.....	17.67	.....	.....	.....	0.52	tr	.....
Fe_2O_3	.....	.....	.....	.....	0.44	2.89	9.72	.....
FeO	.....	.....	7.25	6.15	.....	.....	29.23	5.16
MgO	.....	.....	0.05	1.67	0.43	0.20	1.40	0.12
CaO	4.36	.....	12.26	10.33	18.81	1.81	0.53	0.43
SrO	12.11	.....	.....	.....	.....	8.40	.....	.....
BaO	1.59	.....	.....	.....	.....	6.75	.....	.....
MnO	.....	.....	1.20	2.91	0.45	1.99	3.22	9.95
Na_2O	.....	19.66	13.82	12.43	10.76	14.00	4.74	9.16
K_2O	.....	.....	0.48	0.89	2.52	1.42	0.43	4.94
CO_2	28.38	.....	.....	.....	.....	.....	.....	.....
Cl	.....	.....	1.21	1.32	.....	.....	.....	.....
F	.....	.....	.....	.....	.....	.....	.....	.....
H_2O	5.55	3.80	0.91	0.50	5.61	0.67	0.47	.....
Total	100.00	100.30	99.25	98.89	99.74	100.04	100.10	100.65

TABLE II—continued

	(9)	(10)	(11)	(12)	(13)	(14)	(15)	(16)
SiO_2	34.06	29.13	27.58	27.61	0.47	40.26	49.39	30.76
TiO_2	46.26	37.33	11.15	12.71	50.24	1.92	1.91	40.34
ZrO_2	.....	2.00	0.35	0.20	0.04	12.72	.....	.....
Ce_2O_3	0.32	.....	18.02	8.79*	33.17	.....	.....	0.17
Yt_2O_3		.....	.....	1.36†	1.54	.....	.....	
Al_2O_3	0.90	.....	1.47	0.13	.....	.....	21.83	
Fe_2O_3	.....	.....	0.99	.....	.....	26.43	3.37	0.10
FeO	1.03	1.84	.....	.....	.....	.....	....	0.02
MgO	tr	0.75	tr	0.80	.....	2.42	tr	0.72
CaO	0.35	2.10	24.70	27.26	5.08	1.68	4.46	27.50
SrO	.....	.....	3.30	3.56	.....	.....	.....	.....
BaO	.....	.....	tr	.....	.....	.....	.....	.....
MnO	0.02	2.92	tr	0.53	.....	8.28	1.76	0.20
Na_2O	16.20	14.94	6.73	7.18	8.60	.....	10.60	0.83
K_2O	0.28	.....	0.16	0.28	0.43	.....	1.21	0.11
CO_2	.....	.....	.....	.....	.....	.....	.....	.....
Cl	.....	.....	.....	.....	.....	.....	.....	.....
F	.....	.....	5.99	6.38	.....	.....	....	.....
H_2O	0.33	8.92	1.75	0.51	.....	.....	6.16	.....
Total	99.75	99.93	102.19	102.68	99.57	93.71	100.69	100.75

*$CeO_2 = 8.79$; $ThO_2 = 0.23$

†$(Di, La)_2O_3 = 5.15$

(1) Calcio-ancylite, analyzed by G. P. Chernik; (2) Ussingite, anal. by N. P. Vrevskaja; (3) Eudialyte, anal. by G. P. Chernik; (4) Eucolite, anal. by I. Starynkevich; (5) Yuksporite, anal. by N. P. Vrevskaja; (6) Lamprophyllite, anal. by K. Beloglasov; (7) Aenigmatite, anal. by I. Starynkevich; (8) Neptunite, anal. by L. M. Kourbatov; (9) Ramsayite, anal. by K. Beloglasov; (10) Murmanite, anal. by I. D. Starynkevich; (11) Rinkolite, anal. by K. A. Nenadkevich; (12) Lovchorrite, anal. by I. D. Starynkevich; (13) Loparite, anal. by I. Knipovich; (14) Astrophyllite, anal. by K. Beloglasov, incomplete; (15) Ranite, anal. by N. P. Vrevskaja, a mixture of pectolite and "spreustein"; (16) Sphene, anal. by V. A. Smirnov.

Table III. Properties of Some of the Minerals of the Kola Penninsula

Name of Species	System	Occurrence	H	Sp. gr.	Color	Streak	Elongation	n_g	n_m	n_p	$n_g - n_p$	Sign
Calcio-ancylite	Rhombic	Indistinct crystals	4	3.82	Brownish yellow	White						
Ussingite		Fine grained	6–7		Violet	White						
Pectolite	Monoclinic	Radiated	5		Grayish white	White	+	1.643	1.642	1.6098	0.0332	+
Yuksporite		Platy, Fibrous	5		Pink, Red	White	–				0.0166	+
Titano-elpidite	Rhombic	Xls. elong. ∥ to *C*	6.5	2.55	Brown Pink	Brownish		1.698	1.686	1.681	0.017	+
Lamprophyllite	Rhombic ?	"	2–3	3.35	Yellow	Yellowish	+		1.75		0.0326 to 0.040	+
Rinkolite	Monoclinic	"	5	3.40	Brown Green Yellow	Light yellow	–	1.651 1.681	1.645 1.667	1.643 1.662	0.008 to 0.019	+
Lovchorrite		Amorphous	5	3.32	Brown Yellow	"			1.653			
Manganneptunite	Monoclinic	Crystals	5	3.20	Red	Orange-red	+		1.73			
Ramsayite	Rhombic	Xls. elong. ∥ to *C*.	6–6.5	3.44	Brown, Red	Pale yellow	+			>1.83	nearly 0.091	–
Loparite	Pseudocubic	Twins	5.5	4,77	Black	Red-brown						
Murmanite	?	Tabularmasses	2–3		Violet	Pale violet			1.735			

TABLE III. (Continued)

NAME OF SPECIES	AXIAL ANGLE	DISPERSION	OPTICAL ORIENTATION	PLEOCHROISM	COMPOSITION	REMARKS
Calcio-ancylite					Carbonate of cerium and the alkaline earths	Near ancylite from Greenland with Sr partly replaced by Ca and Ba.
Ussingite					Hydrous aluminum, sodium silicate	Similar to material from Greenland.
Pectolite	53°		$n_g=b$; n_p nearly $\|\|$ to C		(Ca, Na, H_2) SiO_3	
Yuksporite	Variable 46°–75.5°		Plane of optic axes in elong.	n_p=yellowish pink; n_m and n_g=pink. yellow	Near pectolite but more Na and K.	Fine fibrous structure makes optical determinations difficult.
Titanoelpidite		$\rho > v$	$n_g=a$; $n_p=b$	n_m=yellow; n_p=uncolored	Hydrous titano-zircono-silicate of sodium	Differs from Elpidite in having more TiO_2 than ZrO_2.
Lamprophyllite	40°			$n_g > n_m > n_p$	Titano-silicate of cerium, sodium and the alkaline earths	Named and described by Ramsay.
Rinkolite	45°–88°	$\rho > v$	$n_p \wedge c$ 1.5–3.5°; $n_m=b$.	$n_g > n_m > n_p$	Titano-Silicate of cerium, calcium, strontium and sodium.	Belongs to Mosandrite-Rinkite group.
Lovchorrite					"	Partly isotropic, partly anisotropic.
Manganneptunite			$n_g \wedge c=20°$; $n_m=b$	$n_g > n_m > n_p$=orange yellow	$R_2{}^{I}R^{II}Si_4O_{12}$	High content of manganese.
Ramsayite	49.9°	$\rho > v$	$n_p=a$; $n_g=c$	n_g=pale yellow; $n_m=n_p$= pale orange	$Na_2O \cdot 2TiO_2 \cdot 2SiO_2$	Belongs to Lorenzenite group.
Loparite					Titanate of cerium, calcium and sodium.	Belongs to Perovskite group.
Murmanite	Biaxial		$n_p \perp$ to cleav.		Titano-zicono-silicate of sodium, iron, manganese and calcium.	Study of the mineral not complete.

CANCRINITE AS A HIGH TEMPERATURE HYDROTHERMAL MINERAL FROM COLORADO

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The material described in this paper was collected by one of the authors (Larsen) in the summer of 1913, in the course of the geologic mapping of the Uncompahgre Quadrangle, Colorado. It came from the area occupied by an unusual group of intrusive, coarse grained nephelite and melilite rocks which are located near Iron Hill near the eastern boundary of the Uncompahgre Quadrangle, about midway between the north and south boundaries and about twenty miles south of the village of Iola and twenty miles southwest of the town of Gunnison, Colorado.

Cancrinite is an abundant mineral in the Iron Hill area in several genetic habits: as an alteration product of nephelite, as a reaction product between nephelite and calcite, as a mineral in contact metamorphic limestone, also probably as a primary mineral in a cancrinite syenite, and again as a hydrothermal replacement of melilite. The latter occurrence will be described in this paper. Sulphatic cancrinite[2] has already been described as a vein mineral from this area.

The material described in this paper was found in the small gulch south of Beaver Creek, about a mile east of the road up Cebolla Creek and about one-quarter of a mile south of Beaver Creek. The country rock is uncompahgrite, a coarse to giant-grained rock made up chiefly of melilite with pyroxene, biotite, magnetite, perovskite and apatite. The melilite of the uncompahgrite of this area is more or less altered to a mixture of vesuvianite, diopside and titaniferous garnet which has all the appearance of a contact metamorphosed limestone. The alteration begins from irregular veinlets and extends out from them.

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[1] Published with the permission of the Director of the U. S. Geological Survey and the Secretary of the Smithsonian Institution.

[2] Larsen, E. S., and Steiger, George. Sulphatic Cancrinite from Colorado, *Am. J. Sci.*, **42,** 332–34 (1916).

A veinlet of the cancrinite bearing rock about six centimeters across cuts the partly altered uncompahgrite. About half of the vein is made up of white to colorless cancrinite in grains that are as much as ten centimeters in length and enclose poikolitically numerous grains of monticellite, dark titaniferous garnet and other minerals. In parts of the veinlet vesuvianite occupies the position of the cancrinite and serves as the matrix for the monticellite. There is also some green hornblende and remnants of perovskite and apatite from the original uncompahgrite. Pale green phlogopite, calcite and brown garnet together with chlorite, and aggregates of zeolites make up much of the borders of the veinlet. The monticellite, vesuvianite and garnet seem to be the closest associates of the cancrinite both in space and in time of formation.

The vesuvianite is brown in color, uniaxial negative, and has the indices of refraction $\omega=1.736$, $\epsilon=1.732$. These indices of refraction are somewhat higher than those commonly given for vesuvianite, ($\omega=1.708$ to 1.720) and are probably due to a comparatively high titanium or iron content.

The monticellite is pale yellow brown and leaches out on weathering. It is biaxial, negative, has a large axial angle, the dispersion is $\rho>\nu$ and easily perceptible. The indices of refraction are $\alpha=1.653$, $\beta=1.669$, $\gamma=1.674$. These are slightly higher (.006) than those given for the monticellite from Arkansas with 6.4% of FeO and MnO.

The cancrinite has a perfect prismatic cleavage; the large cleavage surfaces look much like those of calcite. It has a specific gravity of 2.51. It is uniaxial, negative, and $\omega=1.524$, $\epsilon=1.501$. These data are very near those given for other cancrinites although the index of refraction is somewhat high.

Several grams of the cancrinite were carefully separated by heavy solution and used for the analysis. A microscopic examination of the powder used in the analysis showed a very small amount of a prismatic mineral with a rather high index of refraction and sensibly no birefringence. The sample was carefully analyzed by Foshag with the results shown in Table I, column 1. The molecular ratios are given in column 2. The silica, lime, alumina, magnesia, phosphorus and chlorine were checked by duplicate analyses.

TABLE I. ANALYSES AND RATIOS OF CANCRINITE FROM COLORADO

	Per Cent	Molecular ratios
SiO_2	33.64	.5579
Al_2O_3	29.82	.2918
CaO	8.64	.1540
MgO	0.39	.0097
MnO	tr.	
Na_2O	15.41	.2486
K_2O	0.50	.0053
CO_2	6.79	.1543
P_2O_5	none	
Cl	tr.	
SO_3	0.03	.0004
H_2O	4.61	.2556
	99.83	

The ratios lead to the general formula: $5Na_2O.\ 3CaO.\ 5\frac{1}{2}Al_2O_3.\ 11SiO_2.\ 5H_2O$. W. Eitel[3] in a study of the systems nephelite-$CaCO_3$, and nephelite-Na_2CO_3, found two compounds: 3Ne. $CaCO_3$ and 3Ne. $Na_2Ca(CO_3)_2$ which he believed to be essentially natural cancrinite. The agreement of the analysis of the Colorado mineral with the theoretical composition of the first compound is sufficiently close to indicate that the natural mineral is essentially $3NaAlSiO_4.\ CaCO_3$ (Theoretical composition, Table 2, col. 1). The variations are rather too great for this simple composition however, for in both this cancrinite and the sulphatic cancrinite there is a decided excess of alumina and a deficiency of soda indicating an isomorphous mixture of some more aluminous compound and there is, further, an excess of $CaCO_3$. It was found that the compound $Na_2O.2Al_2O_3.3SiO_2$ (the silicate corresponding to the zeolite echellite) when considered as isomorphous with the nephelite leads to the best agreement with the actual analysis. On this basis the Colorado mineral would have the following composition:

$NaAlSiO_4$	(Nephelite)	57.43
$Na_2Al_4Si_3O_{13}$	(Echellite)	23.25
$CaCO_3$		14.44
H_2O		4.44
		99.56

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[3] *Tsch. Petr. Mitt.*, **38,** 1–38 (1925).

The theoretical composition based on this assumption is given in Table 2, Column 2.

Table 2. Theoretical Composition of Cancrinite

	1	2
SiO_2	32.4	33.6
Al_2O_3	27.5	31.0
CaO	7.9	8.7
Na_2O	16.72	13.7
CO_2	5.4	5.8
H_2O	5.4	4.4

Neither of these interpretations are entirely satisfactory. So far it has not been possible to attribute the variations to albite in solid solution as has been shown to be the cause of the variations in nephelite. It seems quite certain, however, that nephelite or carbonate-nephelite will be found to be an essential constituent.

THE ADDITION AND SUBTRACTION RULE IN GEOMETRICAL CRYSTALLOGRAPHY[1]

Austin F. Rogers, *Stanford University*

The addition or subtraction of the Miller symbols of two faces of a zone taken index by index gives another face of the zone. That is to say faces with the symbols $(h+p.k+q.l+r)$ and $(h-p.k-q.l-r)$ are in the zone $[hkl:pqr]$. This useful fact, now to be proved, may for convenience be known as the *addition and subtraction rule.*

Proof of the Addition and Subtraction Rule

The intercept equations of planes through the origin parallel to any two faces, (hkl) and (pqr), are, in terms of the intercepts a,b,c of a unit face, (111), respectively:

$$\frac{hx}{a}+\frac{ky}{b}+\frac{lz}{c}=0 \quad \ldots\ldots\ldots\ldots\ldots \quad (1)$$

$$\frac{px}{a}+\frac{qy}{b}+\frac{rz}{c}=0 \quad \ldots\ldots\ldots\ldots\ldots \quad (2)$$

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[1] Paper presented at the annual meeting of the Mineralogical Society of America at Ithaca, N. Y., December 31, 1924, under the title, An Interesting and Useful Property of Zones. See abstract in *Am. Mineral.*, **10**, 68 (1925).

Solving each equation for z we have the following equation:

$$c\left(-\frac{hx}{la}-\frac{ky}{lb}\right)=c\left(-\frac{px}{ra}-\frac{qy}{rb}\right)$$

Dividing by c and collecting we have:

$$\frac{px}{ra}-\frac{hx}{la}=\frac{ky}{lb}-\frac{qy}{rb}.$$

Multiplying by lr we obtain:

$$\frac{x}{a}(lp-hr)=\frac{y}{b}(kr-lq).$$

If both sides of this equation are divided by $(lp-hr)(kr-lq)$, the result is:

$$\frac{x}{a(kr-lq)}=\frac{y}{b(lp-hr)}\quad\ldots\ldots\ldots\ldots\ldots\ldots\quad(3)$$

Solving equations (1) and (2) for y in a similar manner the following result is obtained:

$$b\left(-\frac{hx}{ak}-\frac{lz}{ck}\right)=b\left(-\frac{px}{aq}-\frac{rz}{cq}\right).$$

Dividing by b and collecting we have:

$$\frac{hx}{ka}-\frac{px}{qa}=\frac{rz}{qc}-\frac{lz}{kc}$$

Multiplying by kq we obtain:

$$\frac{x}{a}(hq-kp)=\frac{z}{c}(kr-lq)$$

Dividing by $(hq-kp)(kr-lq)$ we have:

$$\frac{x}{a(kr-lq)}=\frac{z}{c(hq-kp)}\quad\ldots\ldots\ldots\ldots\ldots\quad(4)$$

Combining equations (3) and (4) we have:

$$\frac{x}{a(kr-lq)}=\frac{y}{b(lp-hr)}=\frac{z}{c(hq-kp)}\quad\ldots\quad(5)$$

This is the same form as $x/x_1=y/y_1=z/z_1$ which is the symmetrical equation of a right line from the origin through the point with the coordinates, $x=x_1$, $y=y_1$, and $z=z_1$. Equation (5), then, represents a line from the origin to the point with the coördinates, $x=a(kr-lq)$, $y=b(lp-hr)$, and $z=c(hq-kp)$. This line, which is known as a zone-axis, is a line through the origin parallel to the intersection line of the (hkl) and (pqr) faces, since equations (1) and (2) are satisfied by the same values for x, y, and z. The zone $[hkl{:}pqr]$, then, may be represented by the expression $[kr-lq.\ lp-hr.\ hq-kp]$ which is called the zone symbol. The symbol is usually expressed as $[uvw]$.

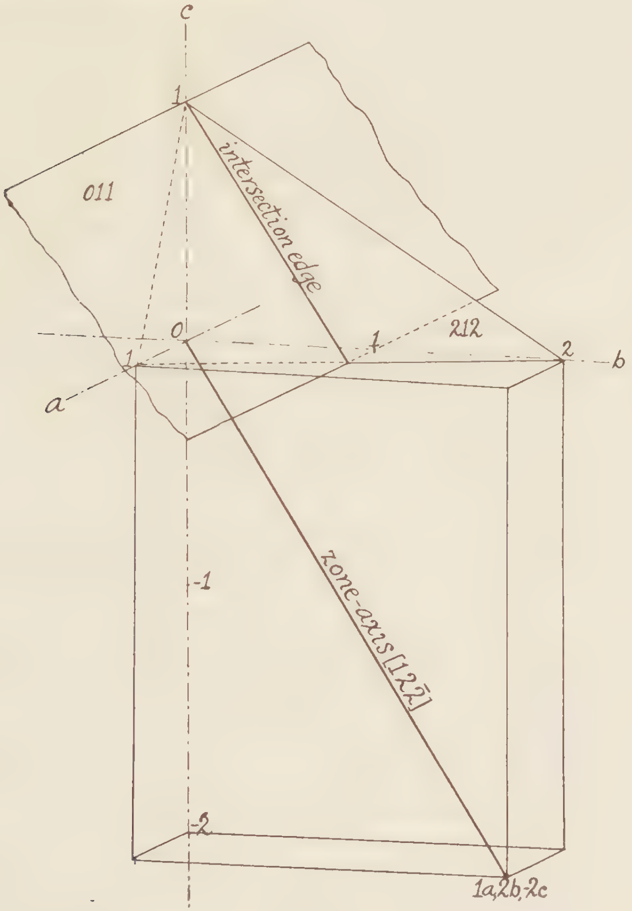

Fig. 1.
The intersection edge and zone-axis of two faces (011) and (212), of an orthorhombic crystal.

The relations indicated are made clearer by Fig. 1. Here the faces (011) and (212) of an orthorhombic crystal intersect in a line parallel to the zone-axis which is a line from the origin to a point with the coordinates $x=(kr-lq)a$ or $1a$, $y=(lp-hr)b$ or $2b$, and $z=(hq-kp)c$ or $-2c$. The zone symbol is $[12\bar{2}]$.

The empirical rule of obtaining zone-indices by cross-multiplying face-indices, thus:

$$\begin{array}{c|ccccc|c} h & k & l & h & k & & l \\ & & \times & \times & \times & & \\ p & q & r & p & q & & r \\ \hline \end{array}$$

is due to the fact that the indices of the zone $[hkl:pqr]$ are $[kr-lq.\ lp-hr.hq-kp.]$

Let (efg) be any face in the zone $[hkl:pqr]$. The equation of a face through the origin parallel to efg is

$$\frac{ex}{a}+\frac{fy}{b}+\frac{gz}{c}=0 \ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad (6)$$

where a, b, and c are the intercepts of the unit face (111). If in equation (6) we substitute for x/a, y/b, and z/c the values of these obtained from equation (5) and expressed in terms of one of them (y/b) we have the following:

$$\frac{ey}{b}\frac{(kr-lq)}{(lp-hr)}+\frac{fy}{b}+\frac{gy}{b}\frac{(hq-kp)}{(lp-hr)}=0$$

This may be simplified by dividing each term by y/b and multiplying each term by $(lp-hr)$. We then obtain the following equation:

$$e(kr-lq)+f(lp-hr)+g(hq-kp)=0 \ldots\ldots\ldots\ldots (7)$$

This is known as the equation of zone control, as it enables one to determine whether any given face lies in a zone with two known faces or not.

If in equation (7) we substitute $(h+p.\ k+q.\ l+r)$ for (efg) we obtain:

$$(h+p)(kr-lq)+(k+q)(lp-hr)+(l+r)(hq-kp)=0 \ldots . (8)$$

And also in the same equation if we substitute $(h-p.\ k-q.\ l-r)$ for (efg) we obtain:

$$(h-p)(kr-lq)+(k-q)(lp-hr)+(l-r)(hq-kp)=0 \qquad (9)$$

Since we find that the algebraic sum of the products of the left side of both equations (8) and (9) is equal to zero, we have definite proof of the addition and subtraction rule.

In the addition and subtraction of indices, $(mh.mk.ml)$ and $(np.nq.nr)$, where m and n are whole numbers, may be substituted for (hkl) and (pqr) respectively, since the above equations are valid when these substitutions are made. This is obvious, for all parallel planes on the same side of the origin are equivalent.

Previous Use of the Addition and Subtraction Rule in Geometrical Crystallography

The addition of the Miller symbols of two faces of a zone taken index by index to give another face of the zone has been made use of to some extent.

(1) To determine the symbol of a face truncating the edge between two known faces. For example, the symbol of the face truncating the edge between the rhombic dodecahedral faces (110) and (101) is (211), $(1+1=2,\ 1+0=1,\ 0+1=1)$. Similarly, the face truncating the polar edges of the unit rhombohedron $(101\bar{1})$ is $(01\bar{1}2)$. The two faces involved are $(10\bar{1}1)$ and $(\bar{1}101)$. $(1+\bar{1}=0,\ 0+1=1,\ \bar{1}+0=\bar{1},\ 1+1=2.)$

(2) Another use of the addition rule is to determine the sign to be given to the indices of a face which has been found by cross-multiplying two zone-symbols. Any two zones necessarily meet in two opposite parallel faces. The face obtained depends upon which zone-symbol is placed first in cross-multiplying. If it is known that the face in question lies between two known faces its symbol may be obtained by the addition of indices.

(3) The addition of the indices of the two faces of a zone to give another face of the zone has been used in the law of complication first discovered by Junghann[2] and independently by Goldschmidt,[3] and developed by Goldschmidt, Fedorov,[4] and Baumhauer.[5,6]

Very little use apparently has been made of the subtraction of the indices of the faces of a zone to obtain another face of the zone. As a matter of fact this part of the addition and subtraction rule is not generally known. I have seen only two references to it. Story-Maskelyne[7] says: "Where $\lambda=\mu\pm1$, the process is simply the addition or subtraction of the indices in the symbols $(h_1k_1l_1)$

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[2] *Pogg. An.*, **151,** 68–95 (1874).

[3] *Zeit. f. Kryst. u. Min.*, **28,** 1–35 (1897).

[4] *Ibid.*, **32,** 446–64 (1900). *Ibid.*, **35,** 25–74 (1902).

[5] *Ibid.*, **38,** 628–55 (1904).

[6] DIE NEUE ENTWICKELUNG DER KRISTALLOGRAPHIE, pp. 129–43 (1905).

[7] Crystallography, p. 70, 1895.

and $(h_2k_2l_2)$. Whence, whether we take the sums or differences of the corresponding indices in two symbols, we equally obtain a symbol for a face belonging to the zone."

And Baumhauer[8] makes the statement: "Die Symbole von zwei solchen Flächen [he is speaking of two faces (hkl) and $(h_1k_1l_1)$ of a zone] werden aber erhalten durch Addition oder Subtraktion der Indices der beiden Ausgangsflächen:

$$h'=h+h_1,\quad k'=k+k_1,\quad l'=l+l_1,$$

$$\text{und } h''=h-h_1,\ k''=k-k_1,\ l''=l-l_1.\text{"}$$

If the addition of indices of two faces of a zone will give another face of the zone, it necessarily follows that the subtraction of indices will also, since addition and subtraction are inverse operations.

Since (hkl), (pqr), and $(h+p.k+q.l+r)$ are in a zone, it is to be noted that the subtraction of the corresponding indices of (hkl) from those of $(h+p.k+q.l+r)$ will give (pqr), the other face in the zone, and similarly, the subtraction of the indices of (pqr) from the corresponding indices of $(h+p.k+q.l+r)$ gives (hkl).

ILLUSTRATIONS OF THE ADDITION AND SUBTRACTION RULE

Fig. 2 represents in gnomonic projection two prominent zones of an hypothetical orthorhombic crystal. The expression for the zone $[\bar{1}01:012:210]$ on expansion becomes $[\bar{2}\bar{1}0:\bar{3}\bar{1}1:\bar{1}01:\bar{1}13:012:123:111:432:321:531:210]$. The intermediate faces such as (123), (432), (321), *etc.*, result from the addition of indices thus: 0,1, 2+1,1,1=1,2,3. 1,1,1,+2,1,0=3,2,1. 1,1,1+3,2,1=4,3,2. And if the faces such as (321), (432), (123), and (111) had been given, the other faces of the zone would result from the subtraction of indices thus: 3,2,1−1,1,1=2,1,0. 1,2,3−1,1,1=0,1,2. 1,2,3−3, 2,1=$\bar{2}$,0,2=$\bar{1}$,0,1.

It should be noted that the addition of indices of two faces gives a face which lies *between* the two given faces, while the subtraction of the indices of two faces gives a face which lies *beyond* the two given faces. For example, (432) lies between (111) and (321) and is obtained thus: (1,1,1+3,2,1=4,3,2), but (321) lies beyond (111) and (432) and is obtained thus: (4,3,2−1,1,1=3,2,1).

The other zone indicated in Fig. 2 is the zone $[2\bar{1}0:201;011]$ which on expansion by the addition and subtraction rule becomes: $[2\bar{1}0:4\bar{1}1:6\bar{1}2:201:413:212:011:\bar{2}32:\bar{2}21:\bar{2}10]$.

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[8] *Fortschritte der Min., Krist., u. Petrog.*, **1**, 23 (1911).

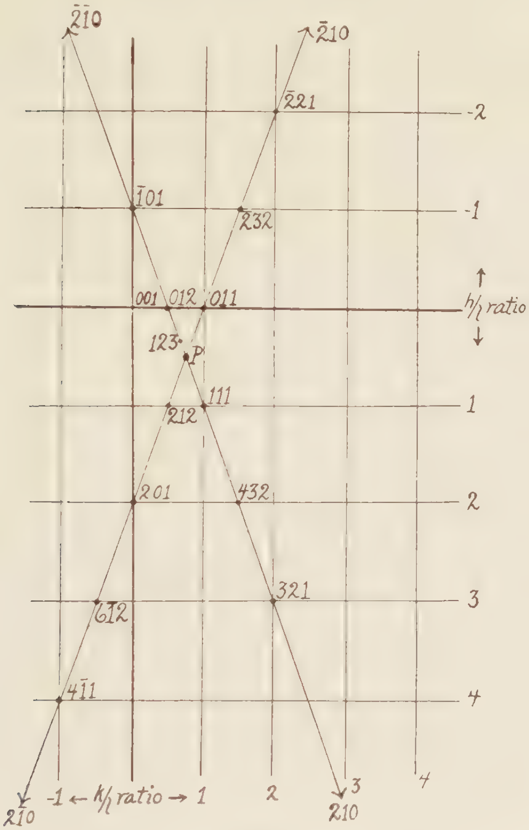

Fig. 2.
Gnomonic projection of two zones [210:012:Ī01] and [2Ī0:201, 011]

General Use of the Addition and Subtraction Rule

The addition and subtraction rule may be used instead of the equation of zone control to determine whether a given face lies in a zone with two known faces or not. This method is based upon the fact that for any face (*efg*) in the zone [*hkl*:*pqr*] the following relation must hold: $mh+np=e$, $mk+ng=f$, $ml+nr=g$ where m and n are whole numbers. With the indices e,f,g, h,k,l, p,q, and r given, it is only necessary to solve the above equations for m and n in order to obtain the result. As an example let us take the following: Is the face (135) in the zone [321:432]? Assigning m to (321) and n to (432) we have the following equations: $3m+4n$

$=1$; $2m+3n=3$; $m+2n=5$. Solving any two of these equations we find that m is -9 and n is 7. Then since

$$-9\times 3,\ 2,\ 1=\bar{27}\cdot\bar{18}\cdot\bar{9}$$

and

$$\begin{array}{r}7\times 4,\ 3,\ 2=28\cdot 21\cdot 14\\ \hline 1\cdot 3\cdot 5\end{array}$$

The addition of these two, index by index, gives us (135), which proves that this face is in the zone [321:432].

In applying this test we may disregard the subtraction part of the rule, for the addition of a negative number is the equivalent of the subtraction of a positive number.

It is also possible by a similar method to determine the indices of a face which lies at the intersection of two zones without determining the indices of the zone.

For example, let us determine the face at the intersection of the zones [123:321] and [212:$\bar{2}$21] of Fig. 2. The face sought (efg) must satisfy two sets of equations since it lies in each of the two zones. For the first zone the equations are $m+3n=e$, $2m+2n=f$, and $3m+n=g$. For the other zone the equations are $2m'-2n'=e$, $m'+2n'=f$, and $2m'+n'=g$, where m, n, m', and n' are whole numbers. We then have: $m+3n=2m'-2n'$; $2m+2n=m'+2n'$; and $3m+n=2m'+n'$. Since we have four unknowns and only three equations it is necessary to express one of the unknowns, say n', as a unit multiplier, $n'/n'=1$. The equations then become:

$$\frac{m}{n'}+\frac{3n}{n'}=\frac{2m'}{n'}-2,\ \frac{2m}{n'}+\frac{2n}{n'}=\frac{m'}{n'}+2,\ \frac{3m}{n'}+\frac{n}{n'}=\frac{2m'}{n'}+1.$$

Solving for $\dfrac{m}{n'}$, $\dfrac{n}{n'}$, and $\dfrac{m'}{n'}$

we obtain

$$\frac{m}{n'}=\frac{15}{8},\ \frac{n}{n'}=\frac{3}{8},\ \frac{m'}{n'}=\frac{20}{8},\ \frac{n'}{n'}=\frac{8}{8}.$$

Then, since

$$\begin{array}{r}15\times 1,2,3=15\cdot 30\cdot 45\\ 3\times 3,2,1=\ \ 9\quad 6\quad 3\\ \hline 24\cdot 36\cdot 48\end{array}$$

On adding we have 24·36·48 or (234)

and since

$$\begin{array}{r}20\times 2,1,2=40\cdot 20\cdot 40\\ 8\times \bar{2},2,1=\bar{16}\cdot 16\cdot\ 8\\ \hline 24\cdot 36\cdot 48\end{array}$$

on adding we have 24·36·48 or (234)

The face common to the two zones $[123:321]$ and $[212:\bar{2}21]$ is therefore (234). This may be checked by a graphic determination of the point *P* in the gnomonic projection of Fig. 2.

It must be admitted that the determination by this method offers no particular advantage over the usual method of cross-multiplication of the two zone-symbols but it is inserted in order to make the discussion more complete and to demonstrate the validity of the addition and subtraction rule.

Use of the Addition and Subtraction Rule in Crystal Drawing

The addition and subtraction rule is a very useful aid in constructing all crystal drawings in which there is a zone-axis normal to the plane of projection, that is to say in certain orthographic projections. Orthographic projections are usually made from stereographic or gnomonic projections, but the method here outlined enables one to dispense with these projections.

The principle of the method depends upon the fact that the projection of every intersection edge in an orthographic projection of the kind mentioned is parallel to the projection of a possible face in the zone which has its zone-axis normal to the plane of the drawing. Since the face sought always lies beyond, and not between, the two given faces the indices must be subtracted.

As a simple example let us make a plan of a trapezohedral (211) crystal of garnet (see Fig. 3). The outline is easily constructed since the edges $(211:21\bar{1})$ and $(121:12\bar{1})$ are parallel to the projections of the possible faces (210) and (120) respectively. Next the intersection edge between (211) and (112) is found by the subtraction of indices to be parallel to (310). $2,1,1\times2=4,2,2$. $4,2,2-1,1,2=3,1,0$. Similarly, the intersection edge between (121) and (112) is found to be parallel to (130). $1,2,1\times2=2,4,2$. $2,4,2-1,1,2=1,3,0$. Subtraction must be used here since in each case the third index must be equal to zero. The drawing may then be completed.

On all the drawings in this article the direction of the intersection edges is indicated by the symbol of the possible face placed directly over the intersection edge.

Another example is a front elevation of a barite crystal with the forms (110), (011), (111), (001), (102), (104), and (122).

Fig. 4. With the axial ratio $b:c = 1.0:1.313$ for barite, lines representing the various faces of the (001) and (011) forms are first drawn. The other lines of the drawing are either vertical and horizontal lines or are parallel to the projection of possible $(0kl)$, $(0\bar{k}l)$, $(0\bar{k}l)$ or $(0k\bar{l})$ faces. The direction of an edge is found by subtracting indices so that the first index is 0. The projection of the edge (102:110) is $(0\bar{1}2)$. $1,0,2-1,1,0=0,\bar{1},2$. The projection of the edge (102:111) is $(0\bar{1}1)$. $1,0,2-1,1,1=0,\bar{1},1$. The projection of the (104:111) edge is $(0\bar{1}3)$. $1,0,4-1,1,1=0,\bar{1},3$. The projection of the (122:111) edge is (011). $1,2,2-1,1,1=0,1,1$. The projection of the (122:110) edge is (012). $1,2,2-1,1,0=0,1,2$. With the data thus found the drawing may easily be constructed.

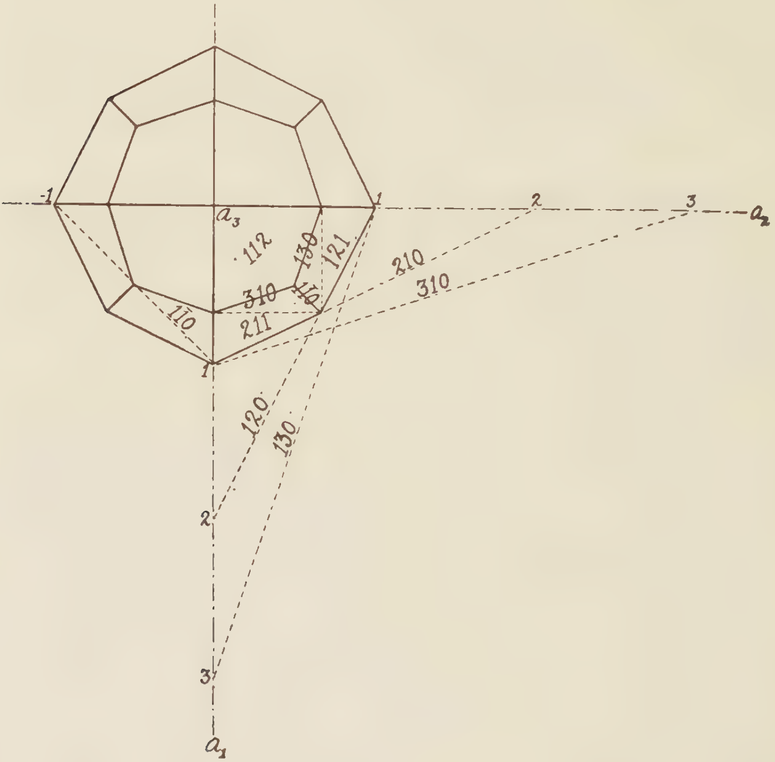

Fig. 3.
Plan of a Garnet Crystal.

Still another example is shown in Fig. 5, which is a side elevation of an augite crystal with the forms (100), (110), (010), and $(\bar{1}11)$. This side elevation may be constructed from a stereographic or gnomonic projection or from a plan and a supplementary projection made from the interfacial angles $(\overline{11}1:\bar{1}11)$ and $(\bar{1}11:010)$ as has been pointed out by the writer in a recent article.[9] In the last case the procedure would be similar to that given for gypsum.[10]

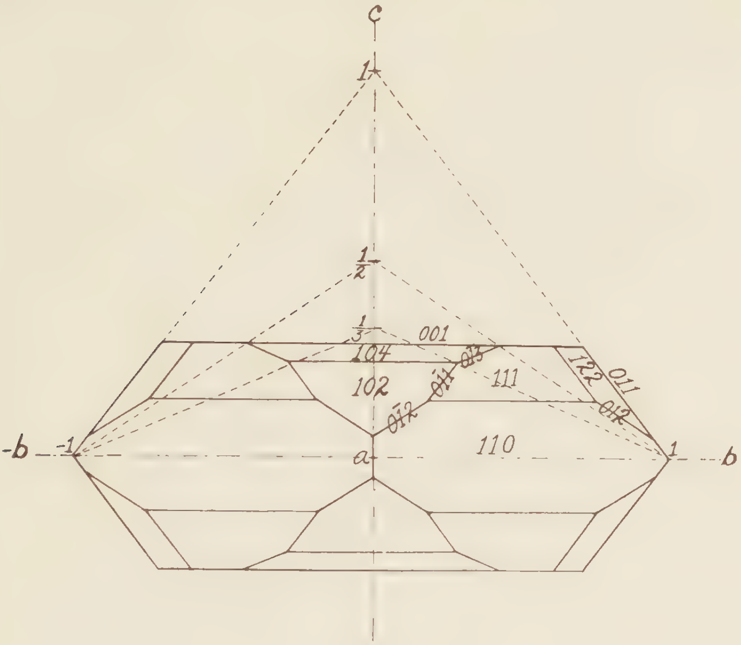

Fig. 4.
Front Elevation of a Barite Crystal.

A more direct method of constructing the side elevation of augite involves the axial ratio *a:c* and use of the addition and subtraction rule. The outline is made by laying off the axial ratio $a:c = 1.09:0.59$ and $\beta(a:c) = 74°10'$. The edge $(\bar{1}11:\overline{11}1)$ is parallel to the projection of the possible face $(\bar{1}01)$. The projection of the edge $(110:\bar{1}11)$ is found as follows: $\bar{1},1,1-1,1,0=\bar{2},0,1$, and the projection of the edge $(\bar{1}11:\bar{1}10)$ is found as follows: $\bar{1},1,1-\bar{1},1,0$

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[9] *Am. Mineral.*, **8,** 19–31 (1923).

[10] *Ibid.* See Fig. 4, p. 25.

=0,0,1. Subtraction is used in both cases since the second index in each case must be zero. Lines are drawn parallel to the traces of the $(\bar{2}01)$ and (001) faces and the drawing may be completed.

A more complicated example is shown in Fig. 6. Here we have an angular elevation of a topaz crystal with the forms: (110), (120), (010), (021), (041), (223), (111), and (221). In the three preceding examples the zone-axis normal to the plane of projection is the *c*-axis, the *a*-axis, and the *b*-axis, so that the direction of the intersection edges of the drawings are parallel to possible (*hk*0), (0*kl*) and (*h*0*l*) faces respectively. In the drawing of Fig. 6 we have a different case. Here the plane of projection is a plane normal to the zone-axis $[1\bar{1}0]$. The lines of the drawing are parallel to traces of possible (*hhl*) and $(\overline{hh}l)$ faces including (110) and (001). In each case the multipliers must be chosen so that the subtraction of indices will give a symbol in which the first index is the same as the second index.

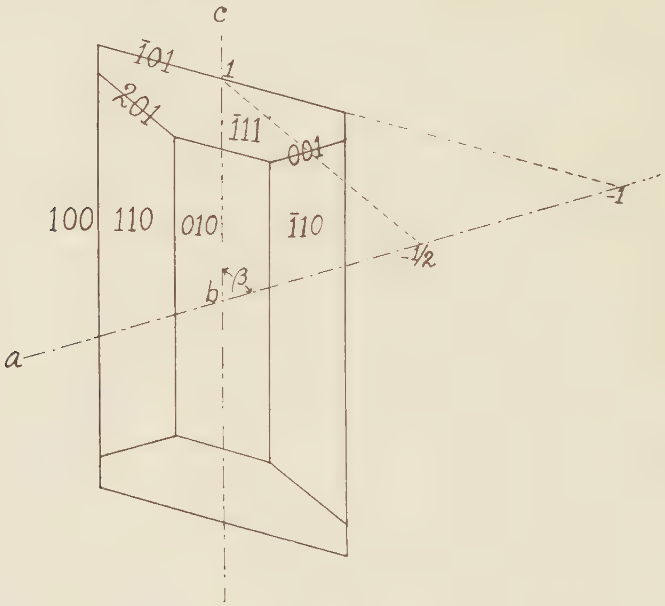

Fig. 5.
Side Elevation of an Augite Crystal.

After the bounding faces (110), (221), (111), (223), ($\bar{2}\bar{2}3$), ($\bar{1}\bar{1}1$), ($\bar{2}\bar{2}1$), and ($\bar{1}\bar{1}0$) and the edge (021:0$\bar{2}$1) are projected, the direction of the intersection edges is obtained as follows: The direction of the (021:120) edge is ($\bar{2}\bar{2}1$). $1,2,0\times 2=2,4,0$. $0,2,1-2,4,0=\bar{2},\bar{2},1$. The direction of the (041:120) edge is ($\bar{4}\bar{4}1$). $1,2,0\times 4=4,8,0$. $0,4,1-4,8,0=\bar{4},\bar{4},1$. The direction of the (041:$\bar{1}$20) edge is (443). $0,4,1\times 3=0,12,3$. $\bar{1},2,0\times 4=\bar{4},8,0$. $0,12,3-\bar{4},8,0=4,4,3$. The direction of the (021:$\bar{1}$20) edge is (223). $0,2,1\times 3=0,6,3$. $\bar{1},2,0\times 2=\bar{2},4,0$. $0,6,3-\bar{2},4,0=2,2,3$. And in the same way the direction of the other edges is found. The drawing may then be completed.

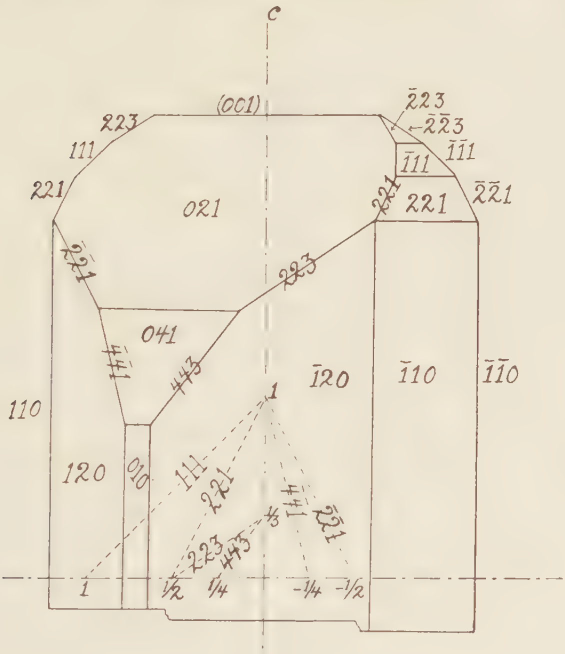

Fig. 6.
Angular Elevation of a Topaz Crystal.

In conclusion the opinion is expressed that the addition and subtraction rule is a useful aid in the problems encountered in the delineation and calculation of crystals.

TETRADYMITE FROM HACHITA, NEW MEXICO

M. N. Short and E. P. Henderson,[1] *U. S. Geological Survey*

A specimen of ore from the Little Mildred mine near Hachita, New Mexico, was sent by Mr. Albert E. Bader to the U. S. Geological Survey for identification. A polished section of the ore was made and studied microscopically by Mr. Short. The ore mineral is homogeneous with the exception of a little native gold. The material was crushed and a preliminary separation of the heavy minerals was made by panning. The concentrate was screened and that part between 40 and 60 mesh was further concentrated with the aid of bromoform solution of sp. gr. 2.85. The concentrate was then analyzed by Mr. Henderson and found to be tetradymite.

Mr. Bader has kindly furnished some notes on the geological occurrence of the ore. The Little Mildred mine is situated in the Little Hatchet Mountains in the extreme southwestern corner of New Mexico, and about 18 miles southwest of Hachita. The altitude of the mine is about 5500 feet. The geological formations consist of a series of tilted and faulted Paleozoic sediments which have been invaded by stocks, sills, and dikes of monzonite, diorite and syenite. The Little Mildred quartz vein is in the metamorphic zone adjacent to one of these intrusions. The outcrop of the vein is about an inch wide and can be traced for about a mile. It strikes northeast and dips southeast. The width in the bottom workings of the mine, 115 feet below the outcrop, is about three feet. The vein is well defined and shows two inches of gouge on the foot wall and one-half inch on the hanging wall. Tetradymite when first discovered in the Little Hatchet Mountains in 1908 was pronounced to be sylvanite.

The gangue is almost pure quartz with which is associated a little black tourmaline. Some angular fragments of dark gray wall rock showing more or less replacement by quartz occur in the vein. The tetradymite occurs as small blebs and in seams scattered through the quartz. The mineralization was evidently a little later than the deposition of the quartz.

The analysis is as follows, a 0.6 gram sample being available for this purpose.

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[1] Published by permission of the Director of the U. S. Geological Survey.

	PERCENT	INSOLUBLE DEDUCTED	RATIOS	
Insol. in HNO_3	3.66			
Te	43.66	45.33	.351	.373=3×.124
S	0.69	0.71	.022	
Se	None			
Bi	50.94	52.90	.254	.254=2×.127
Fe	0.50	0.52	.009	—
Mg	Trace	Trace		
	99.45	99.46		

This checks closely with the theoretical formula Bi_2Te_3. No pyrite was observed; the iron may have been derived from a silicate.

Under the microscope the mineral is galena white, very soft and has moderately strong anisotropism. Etching tests gave the following results:

1 : 1HNO_3 —effervesces vigorously and stains brown to black.
1 : 1HCL —stains light brown to iridescent; in some areas the action is very slow.
KCN (20%)—negative.
$FeCl_3$ (20%)—immediately tarnishes iridescent.
KOH (40%)—stains differentially to dark gray.
$HgCl_2$ (5%) —negative.

These results vary markedly from those given in Davy and Farnham's tables. Inspection of the analyses given in Dana's System of Mineralogy shows that the sulphur in tetradymite varies in different localities from zero to over 5 per cent. This variation in composition probably accounts for the difference in etching behavior of different specimens.

Geologically this occurrence of tetradymite is unique and the fact that it does not occur with other sulphides and tellurides is noteworthy.

PIGEONITE FROM THE TRIASSIC TRAPS OF THE CONNECTICUT VALLEY

JOSEPH L. GILLSON, *Massachusetts Institute of Technology*

In the diabase from West Rock, New Haven, Connecticut, specimen 106 of the Educational Series of rocks prepared by Diller,[1] Pirsson[2] noted the presence of a white "augite" in addition to the normal augite which is the principal dark mineral of the rock. The mineral is readily found in the slide by testing the interference figures of the pyroxenes. A number of the grains yield a very small optic axial angle, while the angle of the principal dark mineral is of the size common to augite. Pirsson stated that this white augite was of wide occurrence in the Connecticut valley. In describing the rock at New Haven he said[3]:

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[1] Diller, J. S.: The educational series of rocks. *U. S. Geol. Survey Bull.* **150** (1898).

[2] Pirsson, L. V.: *Idem*, p. 268.

> Two varieties of pyroxene occur. The one is the usual brownish kind characteristic of this class of rocks; the other is a white or colorless one . . . . the difference between them, since the brown one is light in tone, is not extremely marked . . . . the exact nature of the white augite is not known.

He also mentioned the occurrence of a similar pyroxene in diabase rocks in Sweden, northern England, Brazil, and Nova Scotia, and said that it is characterized by a remarkably small optic axial angle.

Emerson[4] does not mention the occurrence of more than one pyroxene in the Connecticut River traps.

The same mineral was found by the writer in a specimen from the No. 4 Lane quarry in Westfield, Mass. A special trip was made to this quarry in order to collect more material. No doubt now exists but that the mineral is one of the original pyrogenetic minerals of the diabase, and occurs throughout the rock at this point.

Since the identity of this "white augite" never seems to have been established the rock from the Lane quarry was ground, and the minerals were separated in order to determine the optical properties of the pyroxenes. Since the two varieties have nearly identical magnetic properties and specific gravities it was found impossible to separate them into fractions. Moreover the two so closely resemble each other that one could not be isolated under the binocular microscope.

The optical properties of the white augite are as follows:

$\alpha=1.695\pm.003$ Extinction angle $C\wedge Z=45°$ approximately.
$\beta=1.698\pm.003$ $2V=10°54'$ in one specimen.
$\gamma=1.719\pm.003$ $2V=24°16'$ in another specimen.

Dispersion moderate. Optically +, colorless in thin section, and non-pleochroic.

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[3] Pirsson, L. V.: *Op. cit.*

[4] Emerson, B. K.: Plumose diabase and palagonite from the Holyoke sheet. *Bull. Geol. Soc. Am.*, **16**, 91–130 (1905). The geology of Massachusetts and Rhode Island, *U. S. Geol. Survey Bull.* **597** (1917).

These properties are so close to those given for pigeonite by Larsen[5] that without a chemical analysis it seems reasonably certain that this white augite is pigeonite.

The augite has a slate brown color in thick grains and higher refractive indices than the pigeonite, alpha being about 1.701, beta 1.707 and gamma, 1.726. The optic angle is about 60 degrees.

The approximate proportions of the minerals in the diabase at the Lane quarry are as follows:

	Per cent
Labradorite	45
Augite	40
Pigeonite	10
Accessories	5

The occurrence of pigeonite in the diabase at the Lane quarry adds one more interesting mineral to those found there by Shannon.[6]

PROCEEDINGS OF SOCIETIES

PHILADELPHIA MINERALOGICAL SOCIETY

Academy of Natural Sciences of Philadelphia, Sept. 2, 1920.

A stated meeting of the Philadelphia Mineralogical Society was held on the above date, Mr. Millson presiding in the absence of the president and vice-president. Nineteen members and four visitors were present. Nominations for officers for the coming year were presented.

Reports on summer trips constituted the program of the evening. Mr. Biernbaum described a trip to New England, in company with Messrs. Radu and Hoadley. The localities visited included Auburn and Paris, Maine; Grafton and Acworth, N. H.; Portland, Middletown, Danbury, and Meriden, Conn.; and Paterson, N. J. Specimens of the following minerals obtained were exhibited: topaz, apatite, cassiterite, tourmaline, beryl, lepidolite, columbite, and prehnite. Mr. Hoadley spoke of his trip to Montreal and vicinity. Mr. Rosenbaum reported on visits to Paterson, and Cornwall, Pa.

Mr. Trudell then gave an account of a trip to the South Mountain district in Adams County, accompanied by Messrs. Cajori and Gordon. Piedmontite was collected in the metarhyolite near Gladhill, and native copper with cuprite was obtained in veins in the metabasalts.

Samuel G. Gordon, *Secretary pro tem.*

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[5] Larsen, E. S.: The microscopic determination of the non-opaque minerals. *U. S. Geol. Survey Bull.* **679**, p. 225 (1921).

[6] Shannon, E. V.: Famous mineral localities. The datolite locality near Westfield, Mass. *Am. Mineral.*, **4**, 4–5 (1919).

Stilpnomelane and chalcodite at the trap quarries of Westfield, Mass. *Proc. U. S. Nat. Museum*, **57**, 397–403 (1920).

NOTES AND NEWS

In June, 1925, Professor Walter Noddack of the University of Berlin and his assistants, Ida Tacke and Otto Berg, reported that they had found the X-ray spectra of the missing elements 75 and 43 of the periodic tables in the platinum ores from the Ural Mountains. Recently Dr. O. Zvjaginstev of the Platinum Institute of the Russian Academy of Sciences has repeated the experiments of Professor Noddack using rare metals from the same source with negative results. It would seem, therefore, that at the present time the status of these two elements is still in doubt.

Mr. Samuel G. Gordon of the Philadelphia Mineralogical Society attended the Jubilee of the Mineralogical Society (London) as a representative of the Mineralogical Society of America. Following the meetings Mr. Gordon spent some time in Professor V. Goldschmidt's laboratory at Heidelberg, Germany.

Dr. George P. Merrill, head curator of geology in the National Museum, has returned to Washington after attending the Fourteenth International Geological Congress at Madrid. While abroad he visited the museums at Madrid, Paris, Berne, Zurich, Prague, Brussels and London.

Dr. William F. Foshag has returned to the U. S. National Museum after spending some time in Mexico collecting minerals.

Professor Ray C. Treasher of the State College of Washington calls attention in *Science* (Oct. 1, 1926, p. 332) to the advantages of a portable binocular for the determination of opaque minerals in the field. A Leitz binocular with a BSM-A type prism body, mounted on a sliding column was used which with 15× oculars gives a magnification of 45 diameters. The binocular has a long working distance and large field of vision which permits two or three reactions to be observed simultaneously. This feature reduces considerably the time required for the determination.

Dr. Johannes Berger, professor of mineralogy and petrography at the University of Tübingen, has been called to the chair of mineralogy and geology at the Hanover Institute of Technology.